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**CRASHWORTHINESS: AN ILLUSTRATED COMMENTARY ON OCCUPANT  
SURVIVAL IN GENERAL AVIATION ACCIDENTS**

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16. Abstract <p>As the title implies, this is an illustrated commentary on crash survival in general aviation aircraft. Photographs, drawings, and discussion present some basic concepts of crash forces; mechanisms of injury to occupants; and the roles of shoulder harnesses, lapbelts, and seats in attenuating crash forces. Findings in a number of accidents relate seats and restraints to the fate of the occupants.</p> <p>The report is designed to inform the reader of the value of good restraints in crashes of general aviation aircraft. Also it will serve to orient Federal Aviation Administration (FAA) personnel and others to a set of projection slides that may be used wholly or in part in safety presentations to pilots and aviation groups. The projection slides, duplicates of the photographs and drawings in this report, are available from the Aeromedical Education Branch of the FAA Civil Aeromedical Institute.</p>			
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### Preface

Starting with Hugh De Haven, who established the Aviation Crash Injury Research Project at Cornell University Medical School in the forties, the crashworthiness of civil aircraft has been a subject of interest for relatively few accident investigators and laboratory researchers. However, there has been continuing research at the Federal Aviation Administration (FAA) Civil Aeromedical Institute (CAMI) directed at learning about crash impact and improving postcrash survival in civil aviation accidents. Some safety groups in government and industry also have realized the need to implement improved crash protection for aircraft occupants. Those aware of the state-of-the-art technology for occupant protection recognize that the installation and use of improved restraint systems in general aviation aircraft would go a long way toward increasing the chance of survival in many crashes. Because of this, the FAA has mandated the installation of upper torso restraints (along with seatbelts) in certain categories of aircraft and has required their use by crewmembers during takeoffs and landings.

The data and photographs used in this report were collected by several accident investigators and researchers. Some of the findings have been used in the past in training courses for aircraft accident investigators, accident prevention specialists, aviation medical examiners, and others. In response to numerous requests for illustrative material for use in accident prevention and pilot education, we have made the photographs in this report (as projection slides) available to the Aeromedical Education Branch of the Civil Aeromedical Institute for use in its programs. This report, then, represents a somewhat general and simplistic lecture on crashworthiness that may be used in conjunction with the material in the slide sets. It also can stand alone as a source material for readers with an interest in aviation safety.

As stated above, some of this material was collected by others. The efforts of these contributors are appreciated and we hope that they will approve of the manner of use of their findings in this report.

# CRASHWORTHINESS: AN ILLUSTRATED COMMENTARY ON OCCUPANT SURVIVAL IN GENERAL AVIATION ACCIDENTS

## INTRODUCTION

Airworthiness refers to an aircraft's fitness to be operated safely in the air; crashworthiness refers to its fitness to "safely" crash--the ability to protect occupants from injury during a survivable type accident. In a broad sense, crashworthiness includes such considerations as maintaining the structural integrity of the fuselage; attenuating the crash forces acting on the bodies of occupants; preventing items of mass from breaking free and becoming injury producing missiles; providing exits for the escape of occupants after the crash; and reducing postcrash fire, submersion, and other hazardous conditions that may be encountered in an accident.

More than 30 years ago, a crash injury research program conducted at Cornell University (where the term crashworthiness was coined) clearly showed that automobiles and aircraft could be modified to reduce injuries and to improve the chances of occupant survival in many moderate to severe accidents.

Although manufacturers have improved the crashworthiness of automobiles, still over 35,000 lives are lost annually on our highways in accidents involving automobiles, pickup trucks, and vans. Some improvements also have been made in the crashworthiness of light aircraft, yet about 1,500 persons are killed annually. A third or more of these probably could be saved if state-of-the-art crashworthiness technology were implemented to spare occupants the hazards of the crash. Improved means of exit, prevention of fire, increasing the impact resistance of the airframe--all could improve crashworthiness, but the most economical and effective way of saving lives is to attenuate the impact forces acting on the occupants by use of energy absorbing seats and improved restraint systems.

Some engineers have become knowledgeable in designing and building systems for improved crash safety. It is hoped the material in this report will be useful in raising the consciousness of pilots, accident investigators, and others to the value of improved crashworthiness in general aviation.

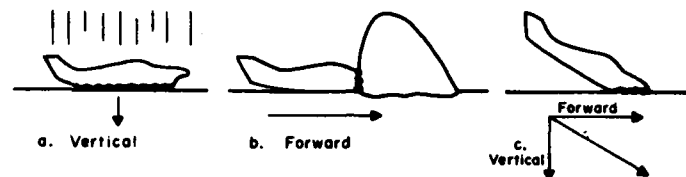


Figure 1

### Crash Dynamics

Newton taught us that "Bodies in motion will remain in motion unless acted on by an opposing force." The body motion possesses energy; the opposing force does work on the body to change its velocity.

As an aircraft crashes it stops, its motion is halted, usually over a short distance by the opposing forces that crush, tear, bend, and break structures. An occupant and all other items of mass within the aircraft will continue their motion along the initial direction of the aircraft with the same velocity until restrained or stopped (acted on by opposing forces) by the shoulder harness, lapbelt, and seat or by striking interior structures.

An aircraft with little or no forward movement, such as in a flat spin, will fall almost vertically (Figure 1a). As the aircraft comes to a halt the structure and occupants will be subjected to decelerations over a short distance in the opposite (upward) direction. Typically, the engine and wings will tend to break down, the gear and lower portion of the hull will crumple, and the fuselage will billow out laterally. The motion of the occupants' bodies will be stopped in a seated buttocks-to-head (vertical) direction.

When an aircraft with forward motion crashes into an object, the velocity will be horizontal (Figure 1b), and the occupants will experience front to back decelerations. In most accidents, occupants are subjected to one major deceleration. The deceleration of the occupant can be divided into vertical and horizontal components just as can be the velocity of the aircraft (Figure 1c).

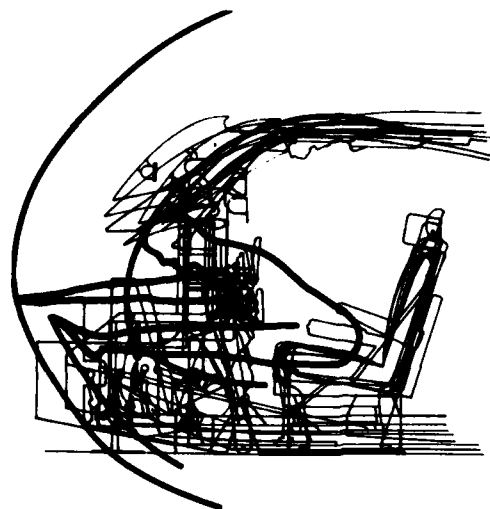


Figure 2

When a seatbelt is worn, the belt will hold the pelvis and keep the lower torso from traveling forward (Figure 2). The upper torso, head, arms, and legs will continue their forward motion. These flailing body parts may strike the windscreen, instrument panel, fuselage structural parts, control wheels, rudder pedals, and other components. This subjects the occupants to impact force of high magnitude and can cause severe or fatal injuries. The head is frequently stopped by the instrument panel, causing fractures of the skull and facial bones, and lacerations of the brain. If the head is stopped by impact with the interior, but the torso continues movement, fracture or dislocation of the neck can occur, perhaps with spinal cord involvement. The chest may impinge upon the control wheel or yoke, causing crushing or penetrating injuries. The forward flexion of the upper torso can be reduced to a large degree by the use of an upper torso restraint--a shoulder harness. The legs and feet flail forward into the rudder pedals or underneath the instrument panel. The vertical component of the deceleration causes downloading on the seat which may fail the seat/floor attachments, the seat legs or the seat pan. The floor may deform and cause seat attachments to fail. In crash injury studies, it is important that the direction of the impact and the magnitude and directions of decelerations experienced by the occupants be investigated, reported, and analyzed to assess the degree of protection provided by an aircraft and its restraint systems.



Figure 3

A general aviation aircraft cabin structure undergoing deceleration on an impact testing track is shown in Figure 3. This is one frame of a 1,000-frames-per-second motion picture. The dummy, restrained by a lapbelt only, has its head being driven into the instrument panel by the force of the deceleration. The unrestrained upper torso continues its forward motion until stopped by the control wheel. This motion, resulting in the head and chest striking forward structures, is typical of occupant dynamics in an otherwise survivable accident--when the upper torso is not restrained.



Figure 4

The pilot shown in Figure 4 received near-fatal head and facial injuries when his aircraft crashed; without an upper torso restraint, his head moved forward and he was severely injured. An upper torso restraint



could have prevented such injury. The magnitudes of forces imposed during a typical severe but survivable accident of this type are very high and the restraint system must do work on the occupant to reduce forces to a tolerable level. An upper torso weighing 80 pounds would exert a force equal to 160 pounds in a 2 G deceleration. At 10 G's, a deceleration which almost any person can survive if properly restrained, the upper torso would have the apparent weight of 800 pounds, requiring much more work done to restrain it. Without a restraint, the upper torso would continue forward, striking the instrument panel and yoke. Deceleration would occur over a distance of a few inches, resulting in very high injury producing forces (G load) to the head and chest. Restraint systems--that is, seats, lapbelts, and shoulder harnesses--should prevent secondary impacts in a crash and reduce injuries.

#### Packaging of Occupants

Principles of attenuating the force of an impact on occupants have been advocated since the early forties and have found wide and successful application in many modern automobiles, in agricultural airplanes, and in several other type aircraft. De Haven, a pioneering engineer in vehicular crashworthiness, compared the safe transportation of people in vehicles to the application of principles used by packaging engineers.

#### PACKAGING PRINCIPLES OF LIGHT AIRCRAFT DESIGN--DE HAVEN 1952

1. ....THE PACKAGE SHOULD NOT OPEN UP  
AND SPILL ITS CONTENTS AND SHOULD NOT  
COLLAPSE UNDER REASONABLE OR EXPECTED  
CONDITIONS OF FORCE AND THEREBY EXPOSE  
OBJECTS INSIDE IT TO DAMAGE.

Figure 5

The shipping container (cockpit or cabin) should not open up or spill its contents (occupants) under reasonable or expected conditions of force (Figure 5). Nor should it collapse on the occupants. Thus, occupants of a crashworthy aircraft should be surrounded by a strong envelope that will resist the force of the impact, but will deform slightly to attenuate the forces generated during the crash.

2. ARTICLES CONTAINED IN THE PACKAGE  
SHOULD BE HELD AND IMMOBILIZED INSIDE  
THE OUTER STRUCTURES BY--INTERIOR  
PACKAGING--PREVENTS MOVEMENT AND  
RESULTANT DAMAGE FROM IMPACT AGAINST  
THE INSIDE OF THE PACKAGE ITSELF.

Figure 6

Articles contained in the package (occupants) should be held immobilized inside the container (cockpit or cabin) to prevent movement (and resultant damage) against the inside of the package itself (Figure 6). In terms of aircraft design, this calls for an effective restraint system that will hold the occupant within the crashworthy cockpit/cabin during the impact. Ideally, the occupant should be encased in a suspended impact-resistant cocoon-like structure that will prolong the duration of the deceleration, thereby decreasing the peak force of the impact. A modern, practical aircraft restraint system consists of a lapbelt, a shoulder harness, and a seat that will resist the force of the impact but will deform without breaking.

3. THE MEANS OF HOLDING AN OBJECT  
INSIDE A SHIPPING CONTAINER MUST  
TRANSMIT FORCES TO THE STRONGEST  
PARTS OF THE CONTAINED OBJECTS.

Figure 7

A third principle of packaging (Figure 7) is that the means (the restraint system) of immobilizing the contents inside the container should transmit forces to the strongest part of the contained article (occupant). In this regard, the seat engages the muscularly padded bony pelvis from below, supporting the body from vertical forces but also functioning to attenuate (through friction) forward decelerative forces. The lapbelt acts on the front and side of the pelvis, and the shoulder harness acts on, rather broadly, the shoulder(s) and the chest.

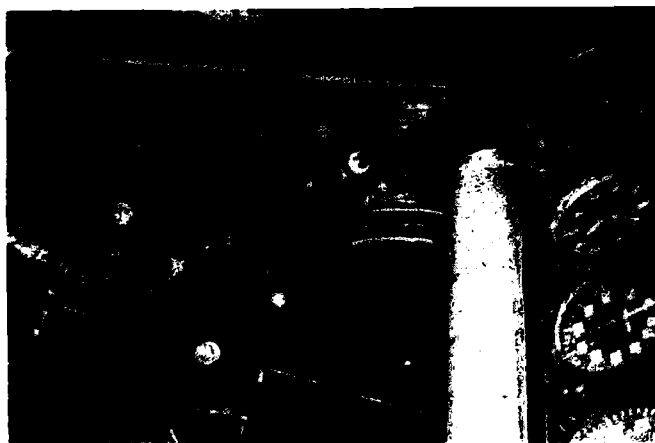


Figure 8

The cockpit of an older aircraft used for aerial application is shown in Figure 8. Impact of the pilot with the levers and knobs shown here--in a severe crash--could result in fractures of bones or possibly in penetrating injuries.

4. PACKAGING STRUCTURES MUST NOT BE BRITTLE OR FRAIL, THEY SHOULD RESIST FORCE BY YIELDING OR ABSORBING ENERGY.

Figure 9

A fourth packaging principle (Figure 9) is that the inside of the container should be designed to cushion and distribute forces over the maximum surface area of the contents and have yield qualities which will increase deceleration time. To accomplish this, some modern aerial application aircraft employ a relatively thin roll of aluminum above the instrument panel so that a broad impact may result if the pilot's head or upper torso strikes the instrument panel during a crash. Also, in these aircraft there are few protruding knobs, handles, corners, or other rigid structures in the forward portion of the cockpit. A crash helmet worn by the pilot can distribute decelerative forces over a broad area of the head, thereby reducing the chance of skull fracture and brain damage.

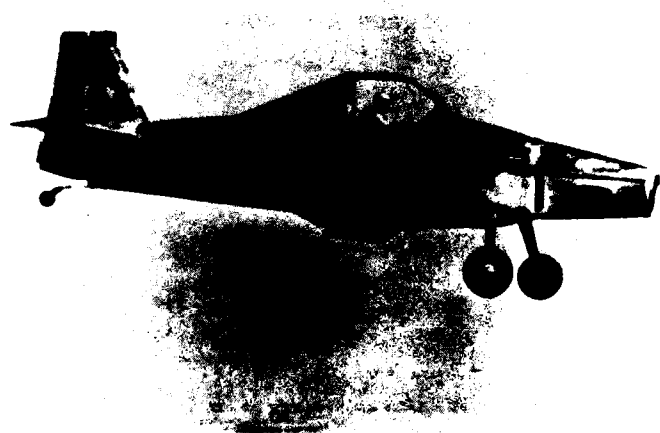


Figure 10

Crashworthiness principles, as advocated by De Haven and Hasbrook, were incorporated in the AG-1 prototype agricultural aircraft designed and built in 1950 at Texas A&M University by Weick (Figure 10). In this aircraft the pilot sat high above and behind the wing. There was a hopper between the pilot and the engine. The structural members of the cockpit were strong--a sturdy outer package. The pilot was restrained by a lapbelt and a double strap shoulder harness. He wore a helmet and there was a large roll of aluminum above the low positioned instrument panel--to distribute the force of any impact should the pilot's head move forward and contact it during a crash.

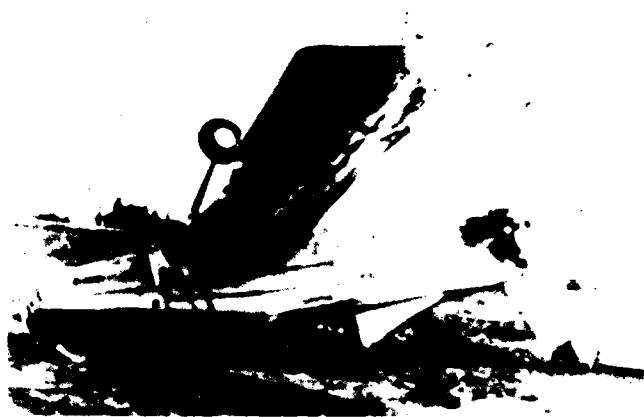


Figure 11

John Paul Jones, an FAA test pilot, flew this aircraft on many occasions to demonstrate its features. One day he got too close to a pole, struck it, and the aircraft crashed inverted (Figure 11). He was able to get out of the cockpit and wave to onlookers to assure them he was uninjured. The crashworthiness features built into the aircraft spared him serious injuries. The dedication note on this picture says, "To my very good friends at crash injury research who designed the cockpit."



Figure 12

Modern agricultural aircraft embody many crashworthiness principles and are the most crashworthy of general aviation aircraft. Interestingly, many of them, as shown here (Figure 12) are similar to the original Texas A&M AG-1. Certainly, pilots engaged in such a hazardous commercial flying activity deserve this type of protection. They frequently walk away from accidents that would have caused severe or lethal injuries to occupants of other types of aircraft.

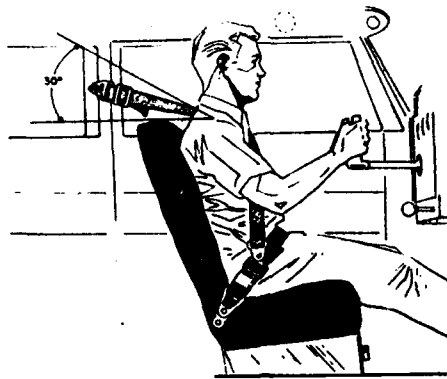


Figure 13

The most economical and effective way to improve crashworthiness of general aviation aircraft is to provide a strong restraint system for each occupant. In its simplest form this includes a lapbelt fit properly to the pelvis, a shoulder harness (preferably double strap) and a seat that will yield but not break (Figure 13).

#### Shoulder Restraints



Figure 14

The aircraft shown in Figure 14 struck trees and fell nose down on the side of a mountain. The two young couples were on their way to a ski holiday. A downdraft drove the plane into a 9,000 foot ridge. The pilot

survived 20 hours and then died of exposure. One of the women had a compression fracture of a lumbar vertebra; the other a fracture in the forearm. This was a severe but survivable accident.



Figure 15

The young man in the right front seat sustained a large, somewhat blunt, penetrating wound of the chest (Figure 15), probably caused when his upper torso was thrown forward against an "open" yoke (control wheel). A shoulder harness may have prevented this fatal injury.



Figure 16

This aircraft (Figure 16) struck relatively level ground and some willow trees. The pilot got out, walked several miles and was then taken to a hospital emergency room. His only injury was a bruised chest.

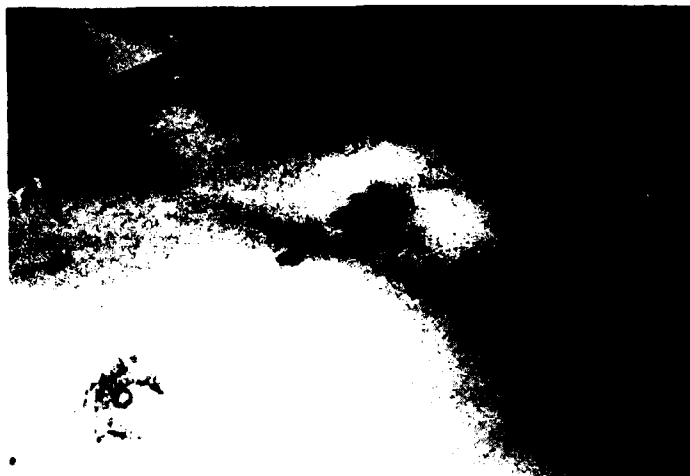


Figure 17

The right front seat occupant, on the other hand, was found dead in the aircraft due to a penetrating wound of the chest and heart (Figure 17). Although this was a survivable accident (pilot survived) the right seat occupant died because of one specific injury. What caused such an injury?



Figure 18

When the control wheels in Figure 18 were examined, two different breaking patterns were noted. The one on the left (pilot's) broke close to the hub as the pilot jackknifed forward and hit the wheel. This resulted in blunt trauma to his chest. The right seat occupant, also jackknifed forward, striking the yoke with his chest and the yoke broke in such a way that a sharp spike remained protruding from the hub. Microscopic examination of a brown film on this spike showed it contained red blood cells, fragments of skin, and pieces of muscle. This "spike" portion of the control wheel

had penetrated the victim's chest inflicting the lethal wound. The use of an upper torso restraint probably could have prevented this lethal injury. A more ductile control wheel that bends but doesn't break could help eliminate the problem illustrated in this accident.

These two accidents demonstrate the importance of upper torso restraint. Pilots should heed such findings concerning the value of shoulder harnesses in crashes. The FAA requirement that crewmembers wear shoulder harnesses (if available) on takeoffs and landings is a rule designed to provide these crews with crash safety protection during critical phases of aircraft operations. Accident investigators should carefully document if shoulder restraints were used and the postcrash condition of each. They, also, should document the injuries and determine their correlation (if any) with the performance of the restraint systems. Such observations can lead to improved crashworthy design of occupant protection devices.



Figure 19

The agricultural aircraft in Figure 19 ran out of fuel, stalled, and struck the ground in a 45° nosedown attitude. The plowed ground tended to attenuate the impact forces. The pilot was provided additional stopping distance by structural crushing, which ended with the engine displaced aft and somewhat above the hopper. Although the pilot had conspicuous shoulder harness and lapbelt contusions and abrasions, he sustained minor injuries.





Figure 20

Interestingly, the shoulder harness attachment brace (Figure 20) was found to be bent forward in the shape of a V and the welds were cracked, showing that the force imposed by the pilot against his shoulder harness was of high magnitude. The shoulder harness attachment was bent and apparently near the point of failure, but it remained intact and the pilot was spared serious injury.

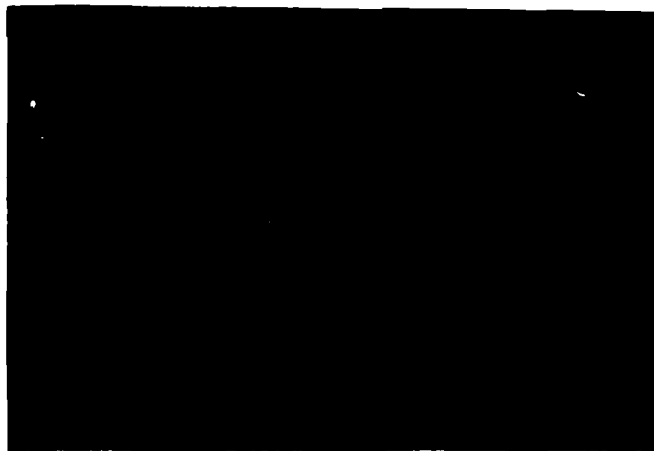


Figure 21

Another aircraft of the same make and model is shown in Figure 21. It struck powerlines, nosed into the ground, and then tumbled end-over-end for about 65 feet. The engine was forced back onto the hopper, the empennage was torn off and the wings torn loose. The crashworthy cockpit--the outer container--was intact. The collapse of the exterior structure showed good energy management and the long deceleration distance indicates that the G level should be low. Substantial tumbling of the cockpit took place after initial impact with the ground and the pilot flailed about violently in the cockpit. The pilot died of the injuries received. Could one expect

the pilot to have survived this severe crash? If properly packaged he might have survived an accident of this magnitude. Why did he receive fatal injuries?



Figure 22

One possible reason is illustrated by Figure 22. Notice that the two fuselage tubes aft of the cockpit were bent slightly at the site where the shoulder harness anchorage was located; the shoulder harness attachment brace broke free at the welds, thereby denying the pilot the full protection of his upper torso restraint. In packaging terms, the article in the package (the pilot) was not held sufficiently immobile to prevent its movement against the inside of the package. An observation of this type of failure might be enough to lead to improvements in the restraint system.



Figure 23

Indeed, this was the case--the broken welds were reported to the manufacturer who fabricated a much more substantial shoulder harness attachment bar (Figure 23); a longer piece of metal was used, the metal wrapped around the

structural bar and welded more securely. Also, flanges were turned up on the brace to further strengthen it so it would resist bending.

It is desirable to have an inertia reel in restraint systems for one to reach forward without restriction. In an accident the impact activates the inertia locking mechanism and the reel keeps the shoulder harness straps from playing out, thus holding the upper torso away from the yoke and instrument panel. Unfortunately, in some crashes the inertia reel has proved to be the weakest part of the restraint system.



Figure 24

For example, Figure 24 shows an inertia reel that failed in a survivable accident. The pilot was severely injured but survived.



Figure 25

In the accident shown in Figure 25, the impact force was somewhat from the right. The woman in the right front seat was said to have been

using her shoulder harness but she received lethal injuries, probably because of her proximity to the side of the fuselage that struck the ground. The pilot survived but had multiple trauma to the head and chest.



Figure 26

His inertia reel was mounted to the sidewall of the aircraft cabin (Figure 26).



Figure 27

The inertia reel pulled free of its mounting (Figure 27). This failure may have resulted from the heavy lateral loading imposed by the pilot on the shoulder restraint. However, even though the inertia reel failed, it may have provided some protection to the pilot before it failed by reducing his impact velocity against interior structures.



Figure 28

An accident like the one shown in Figure 28 attests to the value of the single strap diagonal upper torso restraint. This was judged to be a non-survivable accident because the cabin structures collapsed and partially disintegrated; the pilot was killed. The occupant of the right seat, who was wearing a shoulder harness, survived with numerous broken bones. Apparently the shoulder harness provided protection for his head and chest, saving him from lethal injuries.



Figure 29

The aircraft shown in Figure 29 had power failure on takeoff and crashed into a dirt bank at relatively low velocity. One of the two 17-year-olds in the rear seat was uninjured. The other had unexpected internal injuries. Unrestrained objects in the baggage area struck the back of the seat, driving it forward and causing the lapbelt to compress the occupant's abdomen. The right front seat occupant, who was not using a shoulder harness, received a fracture of the mandible.



Figure 30

This pilot's injuries illustrate the value of the shoulder harness (Figure 30). The bandage on the head covers a large laceration. Notice marks on his upper chest made when he struck the control wheel. He was wearing the shoulder harness and lapbelt.



Figure 31

The abrasions around the waist and the upward abrasion in the middle of the abdomen (Figure 31) attest to the use of the restraint system. This pilot made enough contact with the control wheel to abrade the skin, yet the shoulder restraint prevented a more injurious impact. Had he not used the upper torso restraint, he probably would have received multiple chest injuries, compression and contusion of the heart and lungs, and possibly lethal tears in the heart and large blood vessels. Without the shoulder harness, this survivable accident would probably have resulted in fatal injuries in the pilot.

## Lapbelts

In the very early days of aviation a number of persons were killed when they fell from the aircraft during maneuvers or turbulence. The obvious solution was to use a belt to strap the pilot or occupant to the aircraft. Thus, the use of a lapbelt in aircraft was initially for security in flight rather than for protection in a crash. Interestingly, more people probably are spared injury in air carrier aircraft by use of lapbelts in flight (to protect against injury in severe turbulence) than by their use in crashes because of the rarity of air carrier crashes.

The lapbelt applied to the pelvis implements the packaging principle of applying the restraint to the strongest part of the body.

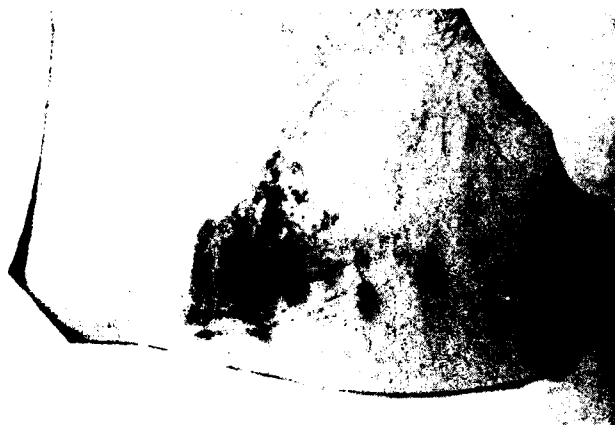


Figure 32

The person in Figure 32 was obviously held by his lapbelt as indicated by the abrasions of the skin over the pelvis.

In making crash injury correlations, accident investigators should always look for bruises and abrasions left by the lapbelt or shoulder harness--on both the dead and the living. A loose lapbelt; an improperly positioned lapbelt; or a seat which may bend downward or break and allow the person to "submarine" (slide forward under the lapbelt) may cause the lapbelt to ride high over the pelvis and compress the soft tissues within the abdomen. If this occurs, it frequently causes internal bleeding from tearing of blood vessels to the gut. There may also be rupture of the liver, spleen, or bowel. A person so injured may die because he cannot be transported to a hospital in time for the required surgery or because the need for surgery is not immediately recognized in the emergency room.

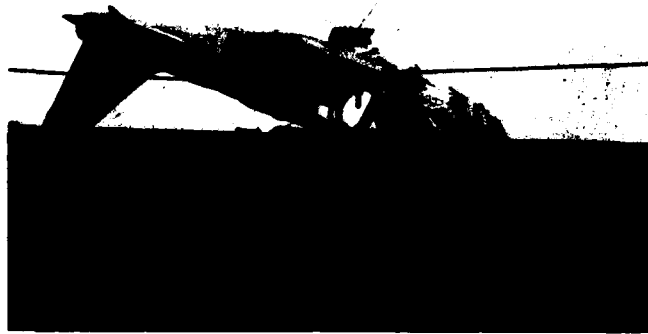


Figure 33

This accident in Figure 33 illustrates the value of the lapbelt in keeping occupants in place. The aircraft with three persons aboard made a downwind takeoff, failed to gain altitude and crashed on top of a building near the airport. The occupant in a rear seat had only a broken finger.



Figure 34

The right seat passenger (shown in Figure 34) had a small cut above his eye. However, the pilot was found on top of the roof, dead from a crushed skull. Why was there this discrepancy in injuries to the occupants? Investigators of accidents in which there are similar disparities in injuries should satisfy themselves as to the sources of these differences.





Figure 35

In this accident an investigator would ask "Was the pilot wearing his lap-belt?" Inspection of the floor of the aircraft revealed a slot (as shown in Figure 35) where the right-hand lapbelt attachment had extended through the carpet and was fastened to the underlying metal structures.

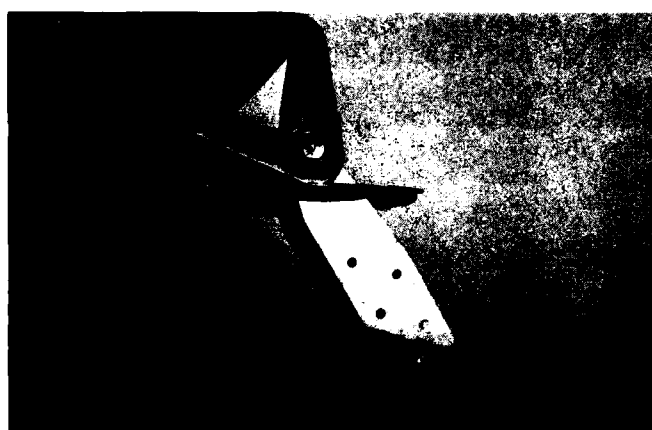


Figure 36

Investigation showed (as in Figure 36) that the lapbelt attachment had pulled free from its anchorage. During impact, sufficient force was applied to the lapbelt (there were no shoulder harnesses) to break its attachment and the pilot was thrown from the aircraft onto the roof of the building. The resulting fatal head injuries were caused by the secondary impact.

Investigators should examine such a lapbelt attachment closely, perhaps even under magnification, to estimate the degree of deformity of each hole to determine whether or not all the rivets or bolts had been in place. Did the restraint fail due to poor manufacture? Was there intrinsic weakness in the materials or attachment configuration?

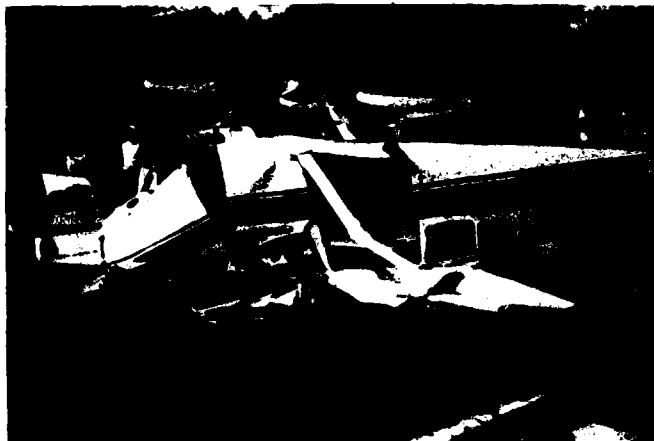


Figure 37

Similar questions should be asked in an accident such as that shown in Figure 37. The aircraft hit electric wires during an attempted emergency landing. Most of the aircraft's forward velocity was dissipated by a large cable; the aircraft then fell upside-down to the ground. Would one expect the pilot to survive this fall? The cabin was intact. Would the lapbelt hold the pilot against the seat and prevent his impact against the inverted top of the aircraft cabin?



Figure 38

Investigation showed that the lapbelt was hanging with one end free from its attachment as shown in Figure 38.



Figure 39

The failed lapbelt attachment is shown in more detail in Figure 39. Note that it was pulled out from its anchorage. The pilot was dead from head and neck injuries. An investigator should ask himself, "Is it reasonable to expect the lapbelt to hold in such an impact?" The engineer should ask himself, "How can the system be strengthened with respect to all the other technical considerations that go into the design and manufacture of an aircraft?" Since this accident, the manufacturer has strengthened the lapbelt attachment in this aircraft model.

The belt webbing is strong; strong enough to adequately restrain occupants in even severe crashes. It may be weakened and fail due to severe weathering, exposure to ultraviolet radiation, chronic abrasion, or chemical deterioration; but the hardware attachments are most likely to be the weakest part of the restraint system.



Figure 40

A problem with restraint attachments is illustrated by the accident in Figure 40. The engine was torn off but the cabin structure remained intact.



Figure 41

The pilot (Figure 41) sustained a long vertical laceration on his forehead. Accident investigators found a corresponding vertical cleavage in his helmet. By absorbing most of the energy of the head impact, the helmet probably saved this pilot's life. One experienced in crash injury correlation would seek to explain the unusual injury pattern.



Figure 42

Examination of the aircraft revealed that the windshield was broken and that the vertical wire cutter bar in front of the windshield was bent forward (Figure 42). Here, then, was the most probable explanation for the vertical cleavage in the helmet and corresponding laceration of the pilot's scalp--the pilot had been thrown forward, striking the wire cutter bar with his head. There was also a broad concavity in the instrument panel showing that it had been struck by the pilot's chest. Analysis provided the crash injury correlation but the question remained, "Since the pilot wore a double shoulder harness and lapbelt, why did he travel far enough forward during the crash to strike forward structures in such a 'mild' crash?"

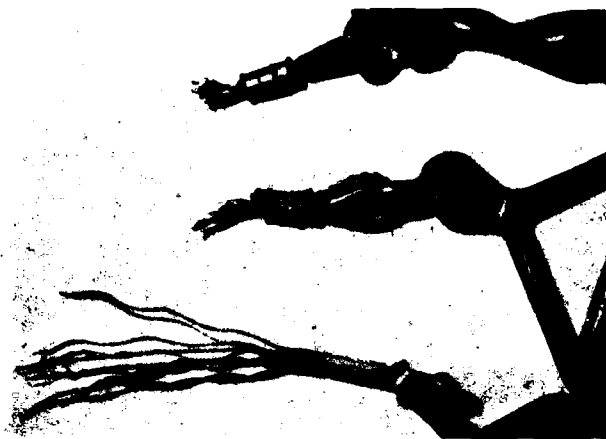


Figure 43

The answer appeared from inspection of the restraint system (Figure 43). The lapbelt ends were attached to wire cables. The cables extended through a bulkhead behind the pilot and were attached to the rigid aircraft frame. The shoulder harness cable led over a pulley behind the pilot's seat and was attached to an inertia reel. The photograph shows all three cables broken. The lapbelt cables had wires which had broken by repeated bending during normal use. The shoulder harness cable wires had broken in a similar manner. Other aircraft of the same model were found to have cables with broken wires. The manufacturer, subsequently, changed the cables and the configuration of the attachments to prevent weakening of the restraint system.

#### Seats

One may not think of the seat as being part of the restraint system, yet it can be an extremely important crash energy absorber. A good seat absorbs vertical and, to some degree, forward loads. A crashworthy seat should carry loads to a certain level without bending or failing; with additional loading, it should progressively deform without breaking. This deformation distributes forces over a longer time period reducing the peak loading. A seat can be too rigid. For example, if one were sitting on an unyielding structure, such as a concrete block, when the aircraft crashed, the block might withstand high loading generated in supporting the body, but the crash force would be transmitted directly to the body, and serious injuries could result. Also, if a seat or its supports break suddenly during impact, the occupant and seat will "bottom out" and decelerate abruptly on the aircraft floor. The stopping distance is unusually short in this type of secondary impact, and the G-loading is high, creating the potential for severe spinal and internal injury.



Figure 44

This was an accident (Figure 44) in which there was heavy vertical loading. The aircraft ran out of fuel and hit an overhead power line wire, stalled, and pancaked into a wheat field. The aircraft dropped straight down in a level attitude. None of the six occupants survived. They all sustained severe spinal and internal injuries. Could impact attenuating seats have prevented their deaths?



after

before

Figure 45

The seats shown in Figure 45 were designed for increased impact attenuation. The seat supports are of a tubular, ductile metal. They are designed with an "S" (preformed bent configuration) so they will bend without suddenly fracturing. This has proved to be an effective impact attenuating design for aircraft seats.



Figure 46

The aircraft in Figure 46 failed to become airborne and during takeoff struck a levee. The deceleration primarily was in a forward direction and one would expect the front seat occupants to receive the most severe injuries. On the contrary, the two occupants in the rear seats sustained fatal injuries and the front seat occupants, who were not using shoulder straps, had severe head injuries but survived.

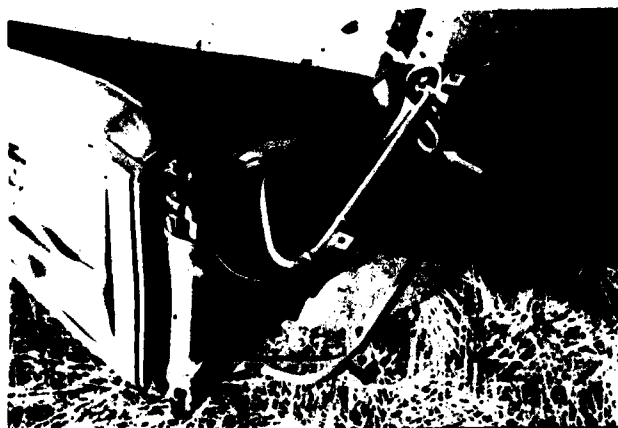


Figure 47

One of the front seats is shown in Figure 47. It is of the tubular ductile metal design previously described and it bent in a desirable manner. Although this was primarily a forward loading accident, the bending of the seat frame indicates there was significant downloading. An additional feature was that the outboard seat support was of smaller diameter, and bent more readily than the inboard support. The differential bending (lateral displacement) could cause the occupant to roll into, rather than out of, the diagonal shoulder harness.

However, it also could cause lateral deflection of the vertebral column and increase injury. Differential lateral bending of seat supports should not be necessary in a properly designed complete restraint system.

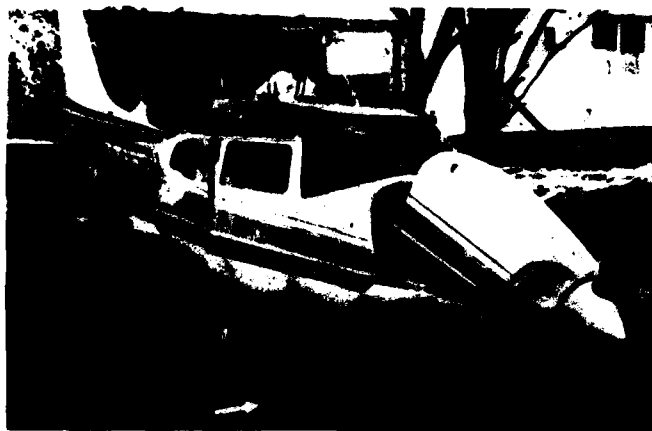


Figure 48

Investigators noted that the six occupants of the aircraft shown in Figure 48 received injuries out of proportion to the impact and severity of damage to the fuselage. They also found that the cast alloy supports of each seat had fractured (Figure 49).



Figure 49

This type of failure occurs suddenly and the occupant is subjected to greater peak loading during secondary impact with the cabin floor or other structures.





Figure 50

A typical failure in a cast alloy seat support is shown in Figure 50. Although the metal is strong, it does not bend or yield progressively. When it fails, it fails suddenly, and potential energy absorption is lost.

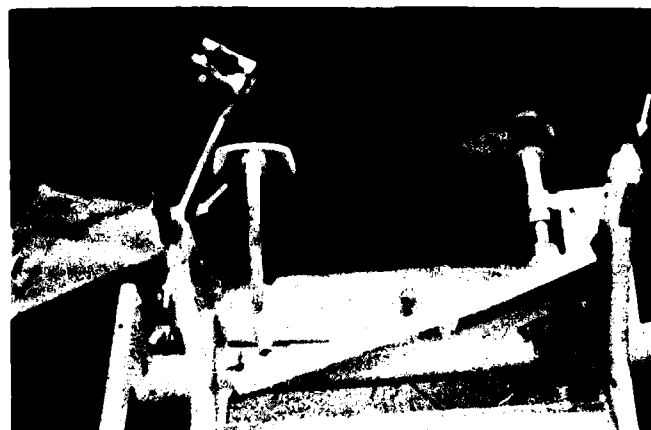


Figure 51

Similarly, loading and twisting of the attachment of the seat to the track can cause the brittle metal to fail (Figure 51) so that the seat and its occupant are free to flail about in the cabin.

The need for strong energy absorbing seats cannot be overemphasized. Not often considered is the fact that, in a crash, the shoulder restraint and the lapbelt will direct some of the forward loading into downward loading on the seat. Some restraint systems may depend entirely on the seat for their basic strength.

Lapbelts attached to the seat (rather than to the aircraft frame) require that the seat withstand the entire loading of the occupant as transmitted by the seatbelt.



Figure 52

Figure 52 shows a seat with the shoulder harness leading through the seat back and attaching to an inertia reel at the bottom of the seat back. For full protection during an impact this seat back must not fold forward and the seat suspension must bear the occupant loading into the shoulder harness.

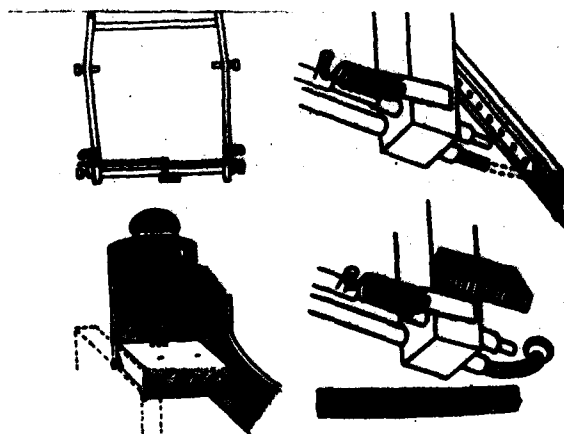


Figure 53

In addition, this particular restraint-seat design (Figure 53) is complicated by the suspension of the seat on axles with rollers in channels on the sidewall and center pedestal as depicted. The integrity of the seat and the restraint system depends on these axles and side channels bearing the crash loads. During an impact an occupant's loading

into the shoulder harness will increase the loading on the seat as well and impart a forward rotary motion which will put great force on the front rollers and axles. Further complicating this seat design is the fact that the fuselage tends to billow out during a crash, displacing laterally the seat track channels and extending the axles, so that they may more readily bend or break under the loads.



Figure 54

Such a seat attachment failure is shown in Figure 54, by the bent and broken seat supports (arrows). As mentioned before, failure of the seats leads to increased occupant injuries from secondary impact and is a departure from desirable occupant packaging principles.



Figure 55

As discussed before, a seat that is rigid may offer little crash energy attenuation of occupant impact. Figure 55 shows an aircraft with an intact fuselage, yet the two occupants had severe spinal injuries--out of proportion to the apparent severity of the accident. What caused the

spinal injuries? A clue is the fact that the wing spar is a large rigid metal tube extending through the cockpit between the floor and the seat bottom.



Figure 56

This spar (with the seat removed) is shown in Figure 56.

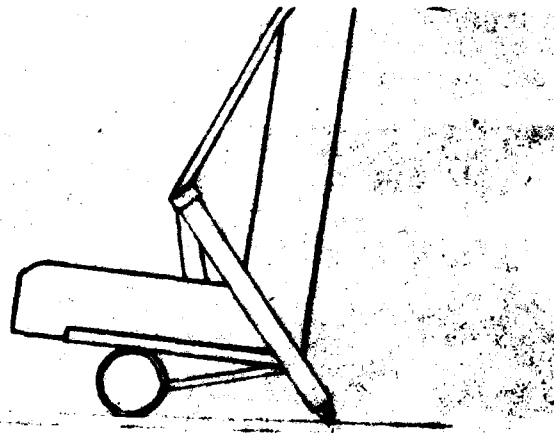


Figure 57

Figure 57 portrays the seat installation. The seat cushion is composed of about 3 inches of soft foam-rubber-like material and sits on a seat pan of plywood. The seat is mounted by metal tracks right on top of the main spar. What degree of protection is afforded by such an arrangement? In an accident, the downward moving lower torso "bottoms out" on the plywood and on the rigid metal tube. The impact force is transmitted directly to the pelvis, spine, and internal parts of the body. Such a configuration provides little or no attenuation of vertical forces.

A most difficult restraint problem is inherent in the use of side facing seats. During a rapid deceleration, an occupant will be unrestrained by the seat itself and, for the most part, will depend for restraint entirely upon the laterally applied seatbelt.



Figure 58

The aircraft shown in Figure 58 landed long and ran off the end of the runway. The structure remained intact and one would expect that the impact was relatively mild, which it was; the pilot was uninjured, three of the four other occupants had only minor injuries.



Figure 59

However, the single occupant of the side facing bench seat (Figure 59) was seriously injured, suffering internal bleeding from a rupture of the liver. During the deceleration, the occupant's body traveled sideways toward the

front of the aircraft. He slid along the seat and was restrained only by a lapbelt, which rode up over the pelvis into the abdomen, compressing and rupturing the liver. For best effect a lapbelt should be pulled down tightly on the pelvis and thighs; a loose belt can move easily over the pelvis and injure organs in the abdomen.

Many people, after an analysis of crash injuries, suggest that passenger seats be turned around to give greater occupant protection. Since the major deceleration is forward in most accidents, the seat back, by cradling the upper torso and head, could afford better protection; but this is true only if the seat and seat tiedown is specifically designed for such loading. The body with its weight and high center of gravity will put additional stress on the seat back at its attachment to the seat pan. The seat will tend to rotate or pitch toward the front of the aircraft; this will cause the front seat leg attachments (aft in aircraft) to be pulled upward and the rear (forward in aircraft) legs to be compressed downward. The dynamics are unique; therefore, the engineering must be unique.

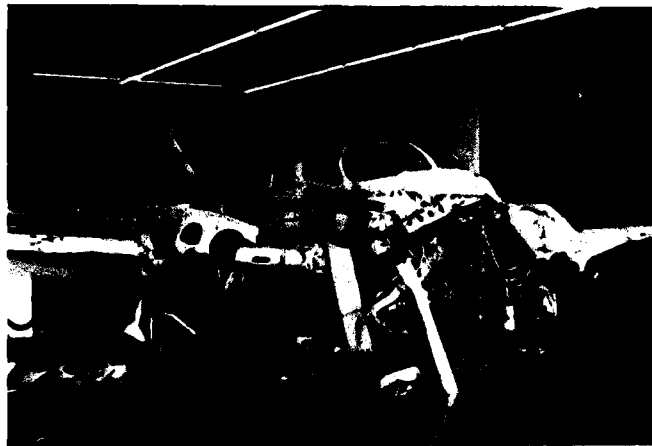


Figure 60

In the accident shown in Figure 60, two of the passenger seats were aft facing. The pilot, with five passengers aboard, failed, before flight, to remove the pin that locked the flight controls. He attempted but was unable to remove the pin during the takeoff roll and the aircraft ran off the end of the runway. The nose wheel went down into a small ditch and the aircraft flipped forward onto its back. The crumpled nose of the aircraft indicates the severity of the forward impact. Of the six persons on board, two were killed; both died of similar neck fractures. The fatalities were in the only aft facing seats in the aircraft. Why this difference in injuries?

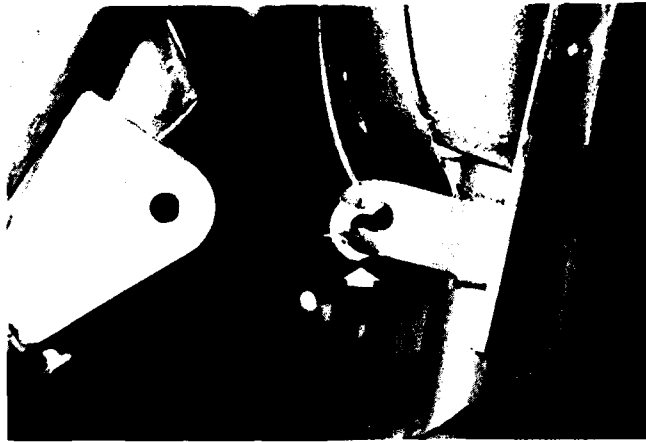


Figure 61

During the deceleration, the upright seat backs were apparently overloaded by the weight of the occupants and failed where the seat back attached to the seat pan (Figure 61). Note the torn hinge metal where the back was attached. Because of this failure, the two occupants slid forward (toward the front of the aircraft) from under their belts and sustained fatal neck injuries in secondary impacts. The lapbelts at the other seats (forward facing) kept the occupants in place. This accident illustrates the differences in occupant dynamics and the need for careful engineering design when aft facing seats are used.



Figure 62

#### CONCLUDING REMARKS

Since the Wright brothers showed that man could conquer the skies, aviation has been an exhilarating experience as illustrated by these Christen Eagles in their exhibition flying (Figure 62). Our airlines

and air cargo operators attest to the practical use of the skies for commerce. Aviation will continue to grow. It is safe but we must make it safer. To do this we should do what we can to prevent accidents. Secondly, because accidents can and do occur, we should assure good crash protection that the state-of-the art can provide. The latter can be done by improving the crashworthiness of our aircraft. Crash injury investigation can identify areas in which improvements in crashworthiness are needed.



Figure 63

Even the Wright brothers had trouble (Figure 63). During a flight by Orville and Lt. Selfridge, the propeller became entangled in a wing strut cable and the plane fell from the sky. Lt. Selfridge was the first person to die in a United States military aircraft accident. He died of a skull fracture when he was thrown out of the Wright biplane during the crash.



Figure 64

Hap Arnold (Figure 64), noting what happened to Lt. Selfridge, wanted greater crashworthiness protection. So he wore his West Point football



helmet while flying. Like General Arnold, pilots should recognize the need for crashworthiness and especially the completeness and serviceability of their restraint systems.

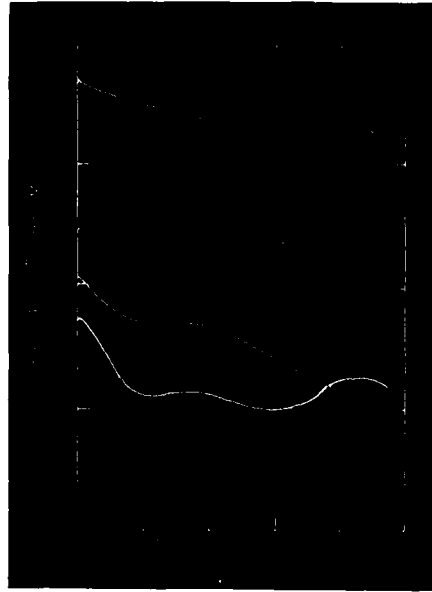


Figure 65

General aviation does not enjoy the reputation of being as safe as other modes of transportation. Based on fatalities per passenger mile, as shown in Figure 65, it is about 20 times more hazardous than bus, train, or airline transportation. One way to enhance general aviation safety is to reduce fatalities by making aircraft more crashworthy. Accident investigators can identify problem areas; manufacturers can improve hardware, especially occupants' restraints; and pilots can see that full use is made of the available restraint systems by all occupants in the aircraft.